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THE CONTROL of the ALFALFA WEEVIL

THE ALFALFA WEEVIL, first officially reported from Utah in 1905, had even then become a pest, doubly serious because of the importance of alfalfa in that region. Always preceded by a wave of apprehension, expressed in quarantines and premature control operations, it has already spread into Idaho, Wyoming, Colorado, Nevada, California, and Oregon. In spite of supposed natural barriers, the weevil has marched steadily onward at the rate of from 10 to 20 miles a year. In the colder parts of its range its depredations have been less serious than elsewhere, and the occurrence of cold weather during the egg-laying period reduces injury to the crop. The weevil is readily controlled by the methods described in this bulletin.

This bulletin supersedes Farmers' Bulletin 741, "The Alfalfa Weevil and Methods of Controlling It," and Farmers' Bulletin 1185, "Spraying for the Alfalfa Weevil."

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THE CONTROL OF THE ALFALFA WEEVIL

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INTRODUCTION

THE ALFALFA WEEVIL[1] is a snout beetle, whose larvae, hatching from eggs deposited principally in alfalfa stems in the spring, feed upon the leaves of the first crop and later upon the buds of the stubble. Completing its growth in summer and fall, it winters in the adult stage in the field and lays eggs the following spring.

Although this insect, widely distributed in the Old World, has attracted little attention there, its brief history in America has been eventful. It appeared suddenly in a region where alfalfa is of great importance, and it multiplied so rapidly, concentrated its feeding into such a short period, and attacked so vital a part of the plant that it became a serious pest. Not only did it inflict severe damage upon alfalfa in certain areas, but it also threatened to involve the entire range of that crop. Since its first appearance in the United States it has spread to nearly all parts of the Great Basin and the Snake River watershed, over large areas of the Colorado and North Platte drainage basins, and into the territory of the Yellowstone and Sacramento Rivers.

It has thus far been impossible to prevent the diffusion of the alfalfa weevil by regulating the production and marketing of alfalfa, because the weevil feeds upon other plants of the clover family. Since none of these is seriously injured and many are unimportant wild species, they do not enter into plans for controlling the pest. The principal remedy, aside from the importation of parasitic insects, is the application of calcium arsenate either as dust or as a spray.

DESCRIPTION OF THE ALFALFA WEEVIL

THE ADULT

The alfalfa weevil is a dark-brown beetle (fig. 1) three-sixteenths of an inch long, with a moderately large snout which points downward from the underside of the head and is partly concealed by it. The brown color of the insect, since it is caused by small brown scales which are easily rubbed off, becomes darker as the black ground color of the body is exposed by wear. Because of this the color of weevils found in the fields ranges from brown to black. Several

[1] *Phytonomus posticus* Gyll.; order Coleoptera, family Curculionidae.

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other small brown beetles, including the clover root curculio,[2] the strawberry root weevil,[3] the clover leaf weevil,[4] and the Aphodius dung beetles, are often mistaken for the alfalfa weevil, even by farmers who are familiar with the latter. A specialist is therefore needed to decide the identity of suspected insects.

FIG. 1.—The alfalfa weevil. Adult. Enlarged

THE EGG

The female beetles, constituting about one-half of all the adults, deposit eggs (fig. 2) in holes which they make with the beak in the green stems of alfalfa and other plants, and in soft, dead stems of all kinds found lying on the surface of the ground. The eggs are laid in clusters, numbering from 4 to 16, but oftenest about 10. They are oval, glistening objects, one-fiftieth of an inch long and three-fourths as wide, bright yellow at first, but more and more dingy in appearance as hatching approaches.

THE LARVA

The larva (fig. 3) is at first a little over one-twentieth of an inch long, of a dingy pale yellow color except the head and a spot behind it, which are black. From the place of hatching it crawls to the tip of an alfalfa plant, and, eating the soft tissue of the growing tip, often completely buries itself in the tunnel thus formed. After feeding there for several days it comes out and attacks the older tissue, sometimes cutting long slits in one or both surfaces of the leaf and at other times making irregular holes in it. Soon after feeding begins, the body, being nearly transparent, takes its color from the contents of the stomach and appears green. The larva sheds its skin two or three times during the feeding period, each time acquiring a larger head, which is at first colorless and later becomes jet black.

FIG. 2.—Eggs of the alfalfa weevil, in split green stem

FIG. 3.—Larva of the alfalfa weevil. Much enlarged

DISTINCTIVE MARKS OF THE LARVA

A faint white stripe down the middle of the back appears after the first molt and becomes

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[2] *Sitona hispidulus* Germ. [3] *Otiorhynchus ovatus* L. [4] *Hypera punctata* Fab.

conspicuous after the second, while a very small but well-marked black collar on the back of the first segment behind the head becomes fainter at the first molt and disappears at the second. These marks serve to distinguish the larva of the alfalfa weevil from that of the yellow butterfly,[5] which in the earlier stages much resembles it, but which has a green head and lacks the white stripe. They may not serve, however, without the aid of experience, to distinguish the larva of this weevil from that of the clover leaf weevil, which also when young resembles it, and whose identification is a matter of some importance in scouting for the alfalfa weevil in new territory.

The alfalfa weevil larva is smaller than that of the clover leaf weevil, its head is smaller in proportion to the body as well as darker in color, and its white body stripe always lacks the pink tinge often found in that of the latter. Nevertheless, third-stage and fourth-stage larvae of the alfalfa weevil, especially where they have recently molted and the head is consequently larger in proportion to the body and lighter colored than normally, may well be confused with first-stage and second-stage larvae, respectively, of the clover leaf weevil which are approaching another molt and are therefore large bodied and have the brown head color fully developed. At such times the alfalfa weevil larva can be distinguished only by its flatter face, more slender body, less rapid taper of the tail end of the body, darker color of the body and of the excrement, less prominent shield behind the head, and more active habits.

THE PUPA AND COCOON

The pupal form is the one in which the change from the larva to the adult takes place. The pupa is contained within a delicate, oval, netlike cocoon (fig. 4), woven of a few white threads and attached, sometimes to the lower part of a green stem, sometimes to rubbish on the ground, and often to the inner side of a curled dead leaf. The pupa within this cocoon is somewhat like the larva in color, but more like the adult beetle in form, becoming still more like it in both respects as it approaches maturity.

HABITS OF THE WEEVIL

WHERE AND HOW THE WEEVILS PASS THE WINTER

When cold weather comes on, the adult weevils creep down close to the ground and into crevices and spend the winter there. Ditch banks and other uncultivated places which are strewn with the litter of dead vegetation often harbor many of them, but their numbers in these situations are insignificant compared with those which remain in the fields to deposit eggs the following spring.

This species has no definite period of hibernation. The adults are quiet when they are cold and active when they are warm. A female taken from the frozen fields into a warm room will feed immediately, and begin laying eggs a few hours later. Many weevils die in the fields during zero weather, but milder winter temperatures seem to have little effect upon them.

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[5] *Eurymus eurytheme* Boisd., the larva of which is known as the alfalfa caterpillar.

EARLY SPRING ACTIVITY OF THE WEEVILS

The readiness with which the weevils resume their activities when subjected to warmth causes them to lay scattered eggs in early spring, many weeks before the regular laying season, and to deposit numbers of eggs in the dry stems on the ground even before they begin climbing up the green plants and feeding upon them. Larvae hatching from these eggs, together with those from eggs laid under similar circumstances during the preceding fall, sometimes attack the plants in numbers large enough to cause serious injury to the crop before the majority of the eggs have been laid, particularly in years when there is an early spring. This early activity in certain climates and seasons tends to blend into the later egg laying and thus lengthen the period of attack upon the crop.


FIG. 4.—Cocoon of the alfalfa weevil attached to dead leaves. Much enlarged

Both the feeding and the egg-laying holes made by the adults admit the spores of Sackett's disease to the plant, causing a blight which is sometimes as serious as the damage wrought by the weevil and is often confused with it.

EGG LAYING OF THE WEEVILS IN LATER SPRING

After feeding for several weeks, running about over the ground, depositing eggs in dry stems, and flying a little, the adults deposit large numbers of eggs in living stems. When the spring opens early they begin egg laying gradually, and the earliest eggs may hatch before the majority are laid. After a late spring the egg laying begins suddenly, probably because the change to warm weather is abrupt.

WORK OF THE LARVAE

The time required for the hatching of the eggs depends upon the temperature during incubation. In warm weather it is from one to two weeks. The larvae become numerous in the fields as early as the first week in May and as late as the first week in June, in the various climates and seasons in which they have been observed. Their abundance is commonly estimated by sweeping the tops of the plants with an insect net, borne upon a wire hoop from 8 to 12 inches in diameter, and counting the larvae so gathered. The number collected in this way varies greatly with different collectors, but after allowance is made for this factor, as well as for the state of the weather, the condition of the alfalfa, and the time of day, there remains a relation between the number which can be so collected and the amount of feeding which is being done by larvae in the field.

It has been estimated that serious damage is threatened when the number of larvae obtained in 100 strokes of a 12-inch net reaches 1,000.[6] In very backward seasons this may not happen before the cutting time of the first crop, and in seasons when the egg laying

[6] WAKELAND, C. SEASONAL VARIATION AS IT AFFECTS THE ACTIVITY AND CONTROL OF THE ALFALFA WEEVIL IN IDAHO. Idaho Agr. Exp. Sta. Bul. 138, 11 p., illus. 1925.

has been prematurely stopped by cold weather the attack of the larvae may cease after they have reached the numbers mentioned. Unless the attack is prevented in some such way, however, the larvae

Fig. 5.—The "turning point in injury" by the alfalfa weevil. The plant on the right is almost uninjured, that in the middle has reached the turning point, and that on the left is nearly destroyed

eat the leaves, especially in the opening tips, so rapidly that the plant is unable to outgrow the injury (fig. 5) and the turning point is passed. Following this, the appearance of the field changes rapidly;

the leaves are consumed until nothing is left but woody fibers, and the tops of the plants are as white as if they had been frostbitten. This condition is shown in Figure 6.

The injury spreads downward, and before the normal time for cutting, if the field is allowed to stand, the whole plant is bare of leaves and the green covering has been stripped from the stems. At this stage, or a little earlier, it is necessary to cut the crop, regardless of its immaturity, in order to prevent severe and perhaps total loss. The results of spring cultivation show at this time. The fields which have been cultivated grow earlier and produce a larger yield before cutting becomes necessary than do those which have been neglected.

FIG. 6.—A field of alfalfa which has passed the turning point. The lower foliage is still sound, but the tops are white and the buds have been killed

A few of the larvae have finished feeding and spun their cocoons before even an early cutting. Most of the others spin their cocoons in June, though a few late larvae are abroad in the field until winter.

When the first crop is removed, if the ground is dry and the weather clear and warm, many larvae, pupae, and adults die as a result of exposure to the heat of the ground. This mortality is increased if the ground is cultivated in such a way as to fill the cracks, crush the clods, and scrape off all remaining vegetation. This in turn is more easily accomplished if the soil has been kept in good condition by manuring and cultivation.

The heat of the soil also probably accounts for a certain amount of flight by the adults during the dry, hot weather beginning in June and ending in August. This flight takes them to grassy and shaded places where they find protection from the heat. It helps to restock fields in which the weevils have been killed, and makes it necessary

to repeat the treatment year after year, and on the borders of the infested district it contributes to the spread of the pest. The flight is not a general movement of the weevils from the fields to seek more suitable hibernation places elsewhere. There is no such movement, and virtually all of the weevils spend the winter in the fields.

WORK OF THE LARVAE IN THE SECOND CROP

If no treatment is given the infested field after haying, the larvae which have been feeding upon the first crop gather upon the buds of the stubble. Although many have been killed by the heat of the ground after cutting, there are still enough to prevent the sprouting of the second crop for a time nearly equal to its usual period of growth. By that time most of them have finished their feeding and growth and have gone into the pupal stage, and there is consequently no attack upon the later growth.

ACTIVITIES OF THE NEW GENERATION OF WEEVILS IN SUMMER AND FALL

At the time of cutting the second crop the fields are full of weevils of the new generation, and the hay cut at this time contains many more weevils than that of the first and third crops. Their activity is greater at night than by day, and this condition continues until the cool weather of September begins. As fall progresses they frequent the plants less and less, and, fortunately, are nearly all on the ground before the threshing of the seed. No live weevils have ever been found in alfalfa seed.

About one-half of the females of the new generation of beetles are ready to deposit eggs by the beginning of winter, at which time egg laying, chiefly in dry stems, has been going on for about a month. Few of these eggs hatch before winter, but some of them hatch during the following spring, and the resulting larvae probably take part in the early attack upon the first crop.

THE ALFALFA WEEVIL IN EUROPE

The alfalfa weevil has been reported from places in Europe, Asia, and Africa, as widely separated as Scotland, the Kirghiz Steppes, India, Algeria, and the Canary Islands, but it is not understood to have been generally or often a highly injurious pest. In southern Europe, the most favorable region so far explored for the purpose of studying and exporting its parasites, it has been comparatively scarce. There is evidence that this scarcity is due largely to farm practices, partly to climatic conditions, partly to parasites, and in some measure to fungous diseases.

HISTORY IN AMERICA

INTRODUCTION AND SPREAD

The alfalfa weevil is believed to have been found by farmers near Salt Lake City in 1903 or 1904. In 1905 it was reported to the Governor of Utah by Judge LeGrand Young, and in 1907 it was recognized as a serious pest by the entomologist of the Utah Agricultural Experiment Station.

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There have been many conjectures as to the manner in which it reached this continent, suspicion resting upon household goods, nursery stock, and the packing material in which crockery and other commodities have been shipped from Europe in considerable quantities to the district where the alfalfa weevil was first discovered. When this question was first raised, however, several years had already elapsed since the arrival of the insect, and it was impossible to trace its means of travel.

Although the manner of its spread is not definitely known, it is believed that the flight of the adult beetles accounts for most of it; furthermore, it is known to be carried by irrigation canals, and presumably by rivers, in freshly cut green alfalfa during midsummer, in clothing which has been worn in the fields during that season, and in vehicles upon which the beetles may alight. Its occurrence upon farm produce can usually be traced to the handling of the latter in contact with freshly cut alfalfa; and its occurrence in vehicles is probably related to that in passengers' clothing which has been worn in infested fields.

It has spread in an ever widening circle at the rate of about 10 to 20 miles each year, apparently without much regard to what are commonly supposed to be natural aids or hindrances to the dispersion of insects. Mountain ranges and great stretches of uncultivated land have failed to stop it, and there is no clear relation between its travel and the prevailing winds.

Three great skips have been made in its progress, one isolated colony having been established at Paonia, Colo., one at New Plymouth, Idaho, and one at Reno, Nev. The method of its travel in these instances is unknown. In effect these leaps have increased its total dispersion but slightly, as the general spread of the insect has now nearly reached the zone in which these localities lie with respect to the original center of infestation.

Within the limits of its present territory (fig. 7) it occurs wherever alfalfa is grown, regardless of altitude and local climate. As a serious pest, however, it seems to be confined to the lower valleys in this region, presumably because of their warmer climate. It is noticeable also that even there it has reached great destructiveness only in the warmer seasons.

FLUCTUATIONS IN INJURY

For the first nine years of its history in America the alfalfa weevil not only spread rapidly, but it is said to have nearly destroyed the first cutting of alfalfa year after year without interruption. In 1917, in which occurred the coldest season since the establishment of the Weather Bureau station at Salt Lake City, it did no damage, and its history since that year has varied with the local weather of the different parts of the infested region.

This variation in damage is explained by the stimulating effect of warmth upon egg production. The nine years during which this weevil was invariably destructive were for the most part abnormally warm during the egg-laying season in April and May, as were also those of the later years in which the damage was serious. The climate of that region is such that only a short time remains, after the

temperature will permit egg laying, before the first crop matures and can be removed from danger. Under such conditions a late spring, by delaying the egg laying, may allow the hay crop to be harvested before enough larvae can hatch to do it much harm. This happens often in the warmer valleys and nearly always in the colder regions.

It might be inferred that in somewhat warmer climates, as, for example, that of the Mississippi Valley, conditions favorable to severe weevil injury will occur oftener than in the Great Basin. But such an inference would be unwarranted, since this point can not be decided by comparing mean-temperature records. Moisture has not been found to have any effect upon the insect except as it influences the temperature. Contagious disease, which is presumably related to conditions of moisture, has not been known to control this pest as it is said to control the clover leaf weevil.

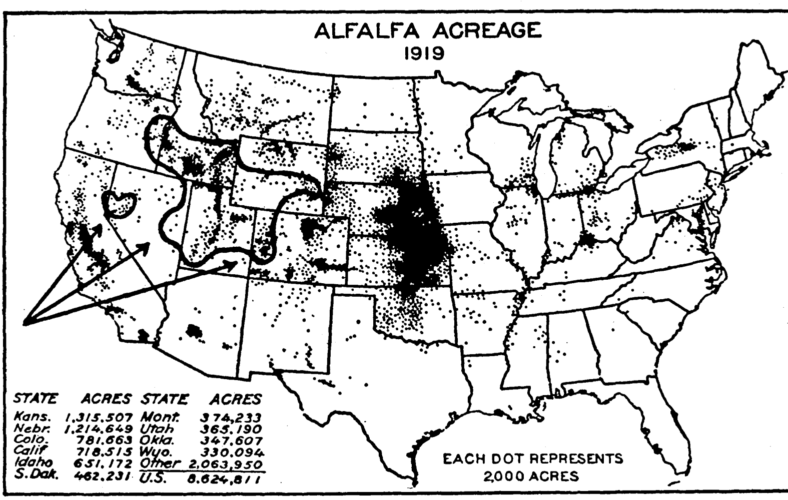

FIG. 7.—Acreage of alfalfa in the United States, and districts (inclosed by heavy lines) infested by the alfalfa weevil

REGIONAL IMPORTANCE OF THE WEEVIL

A large element in the importance of the alfalfa weevil is the significance and value of the alfalfa crop in the region infested. In the infested region the water supply is usually the limiting factor in crop production, reseeding is difficult and expensive, and livestock is frequently the farmers' chief money crop. Alfalfa, which survives prolonged drought, maintains a good stand for many years, and produces a nearly complete ration for livestock, is therefore the predominating forage crop (fig. 7) in the region between the Missouri River and the Sierra Nevadas. The alfalfa weevil, when unhindered, may in favorable climates destroy on the average one-half of the first cutting and nearly all of the second, and in large parts of the stock-growing region of the West this may mean most of the annual yield of alfalfa and at the same time the winter feed of the livestock.

FOOD PLANTS

Although the weevil feeds upon a large number of plants of the clover family, it is not known to damage any crop plant other than alfalfa. At times it injures sweet clover, *Melilotus alba* and *M. officinalis*, growing upon ditch banks adjacent to infested alfalfa, but it has not been known to cause damage in fields of sweet clover. It is believed, though not definitely proved, that the weevil's ability to feed upon wild legumes accounts for the ease with which it spreads through thinly settled regions where alfalfa fields are many miles apart.

CONTROL

Attempts to control the alfalfa weevil have been principally of three kinds: (1) Quarantine measures intended to delay its spread, (2) the importation of foreign parasites, and (3) direct methods of preventing damage to the crop.

QUARANTINES

Whenever a locality is threatened with an invasion of the alfalfa weevil, usually through a new appearance of the insect in a neighboring place, there is a demand that the county and State authorities shall stop its spread by forbidding traffic from the infested region in all commodities suspected of harboring weevils. This has included at one time or another nearly all kinds of farm produce. The regulations commonly adopted at present forbid the entrance, from infested territory, of all hay, cereal straw, and alfalfa meal. They admit alfalfa seed when packed in containers which have not been exposed to contamination, and salt-grass packing when it is certified to have been cut between October 1 and April 1, handled in the field only when the temperature was below 60° F., and not to have been left in the field from another season. Potatoes are admitted when it is certified that they have been screened in loading, packed in clean sacks, and placed in cars free from hay and cereal straw. Nursery stock is required to be fumigated and officially certified. Household and similar goods must be accompanied by the affidavit of the shipper that no alfalfa seed, nursery stock, vegetables, or fruit is included, and no grains or forage except feed for specified livestock. This feed the shipper agrees not to carry past a specified quarantine line.

Common carriers are required to clean all hay and straw from cars from the infested territory which have been used for those commodities, or for livestock, before bringing them into uninfested territory. Machinery and implements which have been used for baling, milling, harvesting, or threshing alfalfa are admitted upon official certificate that they have been cleaned and fumigated. Baggage and emigrant, household, and camping effects, and used farm implements not transported by common carriers, are admitted upon official inspection. Several Western States stop highway traffic from the infested areas and search travelers' effects for alfalfa weevils.

Although quarantine regulations are intended to prevent long-distance spread, no method has yet been devised for checking the gradual spread of the insect around the edges of the infested district.

This spread is accomplished mostly by unaided crawling and flight, and seems likely to carry the weevil wherever alfalfa is grown. The absence of growing alfalfa seems to be no hindrance to the spread, probably because of the large number of other plants upon which the weevil may feed. Mountain ranges do not seem to retard its advance, and in a semiarid country may even aid it by reason of the vegetation which they provide.

PARASITES

The importation of European insect parasites of the alfalfa weevil was begun in 1911. Ten species had been liberated in Utah and one species, *Bathyplectes curculionis* Thoms., was known to have become established, when the outbreak of the World War stopped further importations. This parasite has now spread, with very little artificial aid, throughout most of the territory occupied by the weevil, and in many localities kills as many as 90 per cent of the weevil larvae, or more than are killed by all species of parasites combined in any European locality which has been studied. It works by inserting its eggs into the bodies of the weevil larvae, where they hatch, and the resulting parasitic larvae feed upon the substance of the host, as the larva of the weevil is called in such a case. The effect is not to kill the host at once, but gradually to exhaust its vitality, so that it dies after spinning its cocoon. The parasite then issues from the dead body, and makes a cocoon of its own—small, oval, mahogany-colored and white-belted—within the cocoon of the host. These cocoons may be found in great numbers wherever the alfalfa weevil is abundant, in spring, summer, and fall and until the following spring, when the parasites take on the wasplike form and begin again to deposit eggs in the larva of the weevil.

It is believed that this parasite must destroy enormous numbers of the weevils, but the effect is so long delayed (until the breeding season of the following year), and the rate of increase of the weevil is so rapid that the practical value of this parasitism is not yet certain. Intermittent and unforeseeable control of the pest might do as much harm as good; it would still be necessary for the farmer to carry the overhead expense of spraying for the weevil, and he would often be deluded by a false feeling of security into neglecting preparations for weevil control, and consequently lose his crop. It is hoped that further study of the activities of this parasite may bring forth methods of increasing its usefulness. Meanwhile other species are being imported and studied.

CONTROL BY SPRAYING

However successful the efforts to delay the spread of the weevil by quarantine regulations and to lessen its injuriousness by the importation of parasites, the one tried remedy which the farmer has always at hand and under his own control is spraying with calcium arsenate. By providing a spray outfit and a supply of poison he may at small cost insure himself against the loss of his hay crop by alfalfa weevil depredations. Other methods are sometimes useful, and there are seasons when no treatment is necessary, but the only safe course is to be prepared to spray the alfalfa when its condition

shows that it will be unable to reach maturity without protection against the weevil.

THE TIME TO SPRAY

The "turning point in injury," which in seasons of weevil damage occurs at least a few days, and in seasons of severe injury several weeks, before the first crop is ready for cutting, marks the time when the feeding of the larvae is near its height and conditions are favorable for poisoning them. If possible, it would be best to apply the spray several days in advance of the "turning point," but there is no easily recognizable indication by which to forecast it. In many seasons the date when 1,000 larvae can be collected from the alfalfa in 100 sweeps of a 12-inch insect net may be considered a good time to spray, as it is almost certain that severe injury will follow this concentration of larvae.

Careful watching of the field, coupled with experience, is the only safe guide to the best spraying time. Attempts to connect it with calendar dates, or even with the stage of maturity of the crop, will lead to confusion.

THE TIME TO SPRAY GOVERNED BY WEATHER CONDITIONS

The time of the turning point varies from year to year, depending on weather conditions. If the weevils were affected by these conditions in the same way as the alfalfa, it might be possible to name a definite stage in the growth of the plant at which spraying should be done, but this is not always the case.

In warm seasons the plants get an early start, which tends to postpone the turning point; but since this is more than offset by the rapid development of the weevils, the damage is likely to come early. An extreme case of the sort occurs when the season is dry as well as warm; the drought then retards the alfalfa, while the weevils develop without hindrance, checking the growth when it is still too small for profitable cutting. Under such circumstances spraying yields its greatest returns.

In cold, backward seasons the situation is the opposite of that just described. The growth of the plants is hindered by the weather, but not so much as the weevil's egg-laying, hatching, and feeding, and the crop becomes nearly mature before its growth is halted. In the abnormally late season of 1917, when in Utah March temperatures were delayed 30 days and April and May temperatures 15 days behind the normal schedule, the first crop was fully mature before any injury had been done. The result was the only good first crop since the introduction of the alfalfa weevil. At such times the effect of spraying upon the first crop is least pronounced, and its effect upon the second crop becomes the principal consideration.

A heavy frost in the growing season has but little effect upon the weevil, merely delaying for a few hours the egg laying, hatching, and feeding, but it may seriously stunt the alfalfa plants and put them at the mercy of the weevil larvae somewhat as does the cutting of the first crop. Spraying has been done in such cases, apparently with good results, but this situation is still a matter for experiment.

In the average season the conditions lie between those of the two extremes just described. The checking of growth occurs about

10 days before the first crop is ready to cut, and spraying at that time enables the crop to finish its growth (fig. 8). The value of the crop saved in this way, especially in districts where the scarcity of late water makes the first crop the important one, fully repays the cost of treatment.

Where the spring season is as short as it usually is in the climate of Salt Lake City there is rarely any need for a second application of spray, because there is hardly time for the development of a severe attack between the beginning of egg laying and the maturity of the first hay crop. In a somewhat milder climate, however, an abnormally early spring, followed by cool weather after the hatching

FIG. 8.—First crop of alfalfa ready to cut, 10 days after spraying. The white area is an unsprayed strip

season, may so prolong the attack that a second spraying will be necessary before cutting time. This may be determined in the way recommended for the first spraying.

PROTECTION OF THE SECOND CROP

In well-watered sections of the country, where a second crop can be grown, the profit realized by the first crop is only part of the results of spraying. The greater gain is in protection of the second crop, as shown in Figure 9, from the larvae which gather upon the small buds and prevent all growth during the three weeks or more that their feeding continues. From a comparison of Figures 9 and 10 it will be seen that spraying produces a more uniform second crop than does brush dragging. If the larvae have been poisoned through spraying of the first crop, the second crop sprouts and grows without delay, and no treatment of the stubble is necessary.

STUBBLE SPRAYING NOT RECOMMENDED

Spraying of the stubble has been successfully practiced by a number of farmers, but it requires getting upon the field immediately after cutting, which is not always possible, and a much larger quantity of liquid per acre is needed than if the spray were applied to the first crop. In years when the damage to the first crop is slight it might seem more convenient to cut it first and then spray the stubble, but the results of many trials show that this method is not usually practical. The larvae are most easily poisoned when they are feeding upon the tips of the first crop and not when they are clustered below the surface of the ground upon the buds of the stubble. Stubble spraying can be advised only when earlier spraying has been impossible.

FIG. 9.—Second crop of alfalfa, saved by spraying. The strip of bare stubble near the fence was left untreated at the spraying of the first crop

PREPARATION OF MACHINERY

Because of the large number of nozzles used in spraying alfalfa, rust and scale in the pump and pipes are especially troublesome and should be removed when the machinery is overhauled in preparation for beginning work. The nozzles, hose, and connections and the packing of valves, pistons, and cylinders should be examined in time to obtain and install the necessary repair parts. Spraying is less profitable if too much cleaning and repairing are left to be done after spraying begins, while the crew waits and the weevils destroy the hay crop. Any new machinery which is needed should be ordered months in advance.

THE TRACTION SPRAYER

Two-horse traction-driven machines, having a tank capacity of 100 gallons, and adapted for alfalfa spraying, can be purchased at a cost of about $300. Some of them are entirely satisfactory, and are, on the whole, less expensive than gas-engine outfits, unless the farmer already owns an outfit for orchard spraying, which can be equipped for spraying alfalfa by the addition of a boom or distributing pipe.

THE GAS-ENGINE SPRAYER

The orchard sprayer may be anything from a barrel-pump outfit, carried in a wagon, to a 200-gallon tank, mounted with a gasoline engine and pump on a special frame and truck. Any pump equipped

FIG. 10.—Brush-dragged portion of the field shown in Figure 9. The uneven growth is a characteristic result of this treatment

with brass lining, valves, and pistons, capable of delivering four-fifths of a gallon or more per minute and maintaining a pressure of 75 pounds, can be used for this purpose on a scale suited to its size.

The smallest hand-operated barrel pumps will hardly supply a single nozzle, and can be used only for small patches of alfalfa, but some double-acting hand pumps which have 3 by 5 inch cylinders can deliver as much as 9 gallons per minute and are capable of supporting 10 nozzles. Such a pump operated at 30 strokes per minute will stray an acre in 11 minutes. The same pump when driven by a 2-horsepower gasoline engine at 50 strokes per minute will deliver 15 gallons per minute and easily supply 10 nozzles, each delivering 1⅛ gallons. This rate is 25 per cent above the requirements for an outfit moving 200 feet per minute, and makes it possible to drive 250 feet per minute and spray an acre in 9 minutes.

Modern orchard-spraying outfits usually have pumps of the duplex or triplex type, with small cylinders and short stroke, and are designed to give a comparatively small flow at high pressure. They are less suited for spraying alfalfa than pumps with larger cylinders and longer stroke, designed for larger flow and lower pressure. Seventy-five pounds pressure is enough for successful spraying for the alfalfa weevil, but a better distribution of the poison is obtained at a pressure of 100 to 150 pounds. Higher pressures cause needless wear and strain upon the machinery.

The necessary capacity of an outfit having been decided upon, it remains to select the parts to conform to it and to the conditions under which the work must be done. Capacity is not the only thing to be considered in selecting or assembling an outfit. The truck, tank, pump, engine, boom, and nozzles can be chosen in such a way as to avoid later trouble and expense.

THE VEHICLE

Almost any kind of wagon or truck can be used to haul the equipment. For a light outfit an express wagon or an ordinary farm wagon, preferably with no sides, is satisfactory. If planks are used for the bed, the engine, pump, and jack can be bolted to one of them. If an ordinary wagon box is used, a plank to which the machinery is bolted can be slid into it lengthwise and nailed or bolted in place. For a permanent structure a frame of 4 by 6 inch timber may be fitted to the wagon and a 200-gallon tank mounted with the other machinery upon it. The most convenient homemade truck is a flat rack. Commercial orchard spray trucks, usually furnished with low wheels and broad tires, may be used, but high wheels are better for spraying tall alfalfa, not because they break down less alfalfa, since the harm is only temporary, but because they make it easier to attach the spray boom at the proper height, and cause less jolting of the machinery in driving over rough ground.

THE TANK

Commercial spray tanks are usually in the form of a half cylinder made of redwood, cypress, or steel, with a capacity of 200 gallons. Homemade tanks are usually 50-gallon barrels, four of which, with an engine and pump, can be carried on an ordinary wagon or a flat rack. Two hundred gallons of water is load enough for a team in most fields. If the water has to be hauled a long distance a second team and a thresher tank should be used for that purpose instead of the spray outfit.

The most important item connected with the tank is the agitator. Since the poison is not dissolved in the water but merely mixed with it, it will gradually settle to the bottom of the tank, leaving only a weak mixture to be applied to the plants unless the liquid is stirred constantly and vigorously. For this purpose commercial outfits use a paddle or propeller within the tank, operated by a shaft, sprockets, belt, or drive rod from the pump or jack. In barrels the liquid can be stirred by a paddle or dasher worked by the jack or pump or by hand.

A strainer of 20-mesh brass or bronze screen should be fitted over the opening through which the water enters the tank, and another over the outlet from it which leads to the pump. The former may be at the end of the suction hose, if one is used for filling the tank. If a cloth cover is used to keep the tanks or barrels from slopping over it should be of canvas rather than burlap or any other linty fabric.

THE PUMP

In spray pumps of all sizes certain structural features are important because of the corrosive nature of the liquid and the need of a uniform flow at comparatively high pressure.

The cylinder lining, plunger, valves, valve seats, and other working parts in which a close fit is required, and which also come in contact with the arsenic, must be of brass, bronze, porcelain, or some other substance which is less rapidly corroded by the chemicals than are iron and steel. To maintain the

pressure without waste of power requires carefully fitted valves and properly packed stuffing boxes. All commercial spray pumps are built in this way, but pumps which were intended for other purposes should be refitted when used for spraying.

The suction hose leading from the tank to the pump should be 1 inch in diameter, with a heavy wall to prevent collapse. About 10 feet of it is needed.

Every engine-driven outfit must have a relief valve near the pump, permitting the surplus flow to return to the tank. This regulates the pressure and also acts as a safety valve to prevent the development of dangerously high pressures when the outlet is purposely or accidentally closed.

The pump must have an air-pressure chamber large enough to keep the flow steady and thus insure even distribution of the poison. Its capacity in gallons for a double-acting or duplex pump should be about equal to the number of gallons per minute discharged by the pump, which is much more than the capacity of the chamber usually furnished with force pumps, and even of many spray pumps which are intended to be used with a smaller number of nozzles. Triplex pumps need air chambers only two-thirds as large. The pressure chamber should be attached to the line near the pump, but not between it and the relief valve, and it should be mounted in a vertical position to enable the settlings to drain out. It is best to provide the pipe leading to it with a check valve to retain the pressure in the chamber without strain upon the pump.

A cut-off should be inserted between the pressure chamber and the strainer (described below) to prevent loss of pressure during short stops. A plumbers' stop-and-waste cock is suitable for this purpose, because it opens or closes with a single motion. Its two ends are not alike, and it must be attached so that the closed end is toward the pump when the cock is turned off.

FIG. 11.—Pressure strainer attached to spray outfit

THE PRESSURE GAUGE

A pressure gauge is necessary for good work with either a large or a small outfit, because it is impossible without it to maintain the even pressure which is indispensable for the uniform spread of the poison. The gauge should be attached to the air-pressure chamber, or near it, and at a distance from the relief valve and the nozzles.

THE STRAINER

Clogging of the nozzles by rust, scale, and fibers from the interior of the pump and the pipes can be prevented by inserting a strainer, so constructed that it can be cleaned easily, at some convenient place in the pressure line beyond the cut-off. (Fig. 11.) A 2-inch T is used as the shell, and the pipe from the pump is screwed into its middle opening. The T is turned so that the two other openings point up and down, and a plug is screwed into the lower opening, whence it can be removed to clean out the strainer. The strainer itself is a cone of 40-mesh brass or bronze screen strengthened by crossed hoops of No. 14 galvanized wire, both screen and hoops being soldered to the inside of a 2 by ¾ inch bushing, which is then screwed into the upper opening of the large T so that the cone points down into the T. This bushing is connected with the hose leading to the boom. The spray liquid from the pump enters the shell at the side opening and flows upward through the screen cone and out at the top toward the nozzles, leaving the dirt on the outer, lower side of the cone, from which it can be removed after taking out the bottom plug. A diagram showing the construction appears in Figure 12.

THE ENGINE

The capacity of the gas engine should be about 1 horsepower for each 4 gallons per minute of pump capacity. The power is transmitted to the pump

through a jack, driven by a belt or gears, which should give a gear reduction of about 10 to 1. Some spray pumps are built with a crank shaft or eccentric shaft which takes the place of the jack.

THE BOOM

The attachment for adapting an orchard spray outfit to the spraying of alfalfa may conveniently be made by the following plan, the specifications being those of the Idaho extension entomologist.[7]

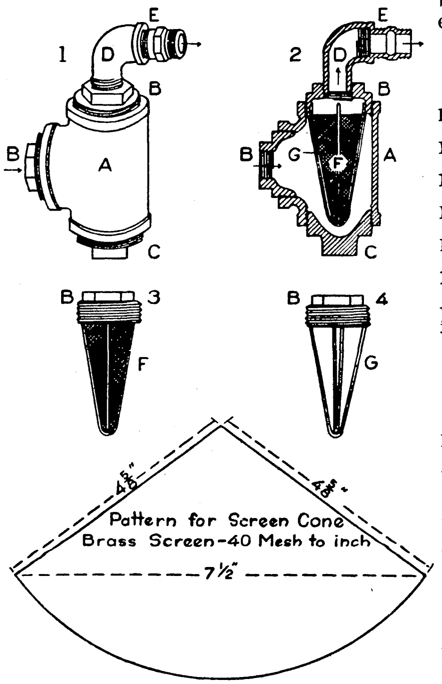

FIG. 12.—Details of pressure strainer. A, 2-inch galvanized T; B, bushing 2 to ¾ inch; C, 2-inch plug; D, ¾-inch galvanized street L; E, ¾-inch hose nipple; F, 7-square-inch 40-mesh brass wire gauze; G, 20-inch No. 14 galvanized wire

LIST OF MATERIALS

A, 2 pieces pine 2 by 4 inches, 6½ feet long.
B, 2 pieces pine 2 by 4 inches, 4 feet long.
C, 1 piece pine 2 by 4 inches, 4 feet long.
D, 2 pieces pine 2 by 4 inches, 3½ feet long.
E, 2 pieces pine 2 by 6 inches, 3 feet long.
F, 2 pieces light halter chain, 7 feet long.
G, 8 pieces ⅜-inch galvanized iron pipe, threaded both ends, 22 inches long, including threads.
H, 8 galvanized iron T's, ⅜ inch.
I, 2 galvanized iron L's, ⅜ inch.
J, 12 bushings, ⅜ to ¼ inch.
K, 10 close nipples, ¼ inch.
L, 2 nipples, ¼ inch, 3 inches long.
M, 10 hollow cones, fine disk nozzles; holes in disks $\frac{1}{32}$ or $\frac{3}{64}$ inch, not larger.
N, 2 J-bolts, ⅜ inch, 6 inches long, threaded 4½ inches.
O, 6 J-bolts, ¼ inch, 3 inches long.
P, 4 bolts, ⅜ inch, 4½ inches long with washers.
Q, 2 bolts, ½ inch, 4½ inches long with washers.
R, 2 pieces spray hose, 4 feet long with clamps.
S, 4 ⅜-inch bolts, 6 inches long.

Screw securely together all pipe connections in the order shown in Figure 13. Place assembled pipe on wood piece A and fasten it by means of three J-bolts O. Wood gives stability to the spray boom and furnishes an easy means of fastening it to the upright pieces so that it may pivot on bolt Q when passing through gates. By removing bolt Q the spray boom may be raised or lowered for various heights of alfalfa. The bolts N and P serve to prevent the wood from splitting and N also furnishes a hook for fastening through the chain.

Figure 14 shows in detail a side view of the framework supporting the spray boom. The upright is braced forward and backward by the diagonal brace D and sidewise by the piece C. The framework is fastened to the roof by four bolts, S, and the entire spray attachment may be taken off by their removal. The piece E extends backward far enough to permit the spray mist to be directed downward without interference with pump or engine.

A rear view of the complete attachment is shown in Figure 15, illustrating the manner of swinging spray booms for passing through gates and of raising and lowering them to cover various heights of alfalfa. Note that there are no braces or other obstructions to interfere with free access to the engine.

The pipe line from the spray pump in most machines is equipped with a two-way valve to which are attached the two lead hoses carrying the liquid to the spray rods. In using the alfalfa attachment one end of a 4-foot piece of spray hose is fastened to one opening in the two-way valve and the other is screwed

[7] WAKELAND, C. EQUIPPING AN ORCHARD SPRAY MACHINE FOR USE IN ALFALFA FIELDS. Idaho Agr. Col. Ext. Circ. 25, 4 p., illus. 1922.

or pushed over the 3-inch nipple and held in place by hose clamps. It is necessary to have the hose about 4 feet long to allow raising and lowering of spray booms.

Twenty feet is the limit of length for the spray boom, owing to the swinging at the ends caused by the wheels of the truck when moving over rough ground. Even when a shorter boom is used it is best to keep on hand one or two extra T's and sections of pipe to repair accidental breaks.

THE NOZZLES

Plain nozzles, designed to give a misty spray, sometimes called hollow-cone, eddy-chamber, cyclone, whirlpool, and cover-spray nozzles, without

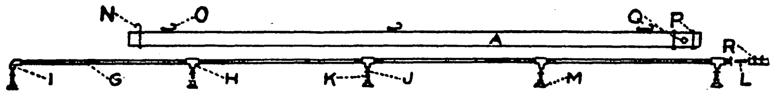

FIG. 13.—Assemblage of boom, for attachment to orchard sprayer

strainers or other complications, are best for this work, since the purpose is to place a fine, even coating of poison upon the upper foliage, where the larvae chiefly feed. This kind of nozzle has a base threaded to fit a $\frac{1}{4}$-inch pipe. On the other end is screwed a brass cap which holds in place the steel discharge disk with its central discharge opening, and back of that a gasket $\frac{1}{8}$ inch thick, within the circle of which is the eddy chamber or whirlpool chamber, which breaks the jet of water into a hollow cone of fine mist and gives the nozzle its various names. Back of this space is the directing disk, a flat piece of metal pierced with one or two holes situated midway between the center and the edge and slanted so that the liquid passing through them gives a whirling motion to the contents of the eddy chamber. This disk should be removable from the body of the nozzle for cleaning, but it is sometimes a part of the single-piece shell. For alfalfa spraying it should not have a central direct hole such as some orchard nozzles have.

The rate of flow of a nozzle depends upon many details of size, shape, and design, but in nozzles of the same pattern it is governed by the size of the discharge opening and the pressure supplied by the pump. Thus a certain nozzle which is in common use, when provided with a $\frac{5}{64}$-inch opening and a pressure of 125 pounds, delivers a little more than $\frac{4}{5}$ of a gallon per minute. For each additional 25 pounds of pressure the flow is increased $\frac{1}{16}$ of a gallon. The same nozzle with a $\frac{6}{64}$-inch opening delivers as much liquid at 75 pounds as with a $\frac{5}{64}$-inch opening at 150 pounds and increases $\frac{1}{8}$ of a gallon for each added 25 pounds.

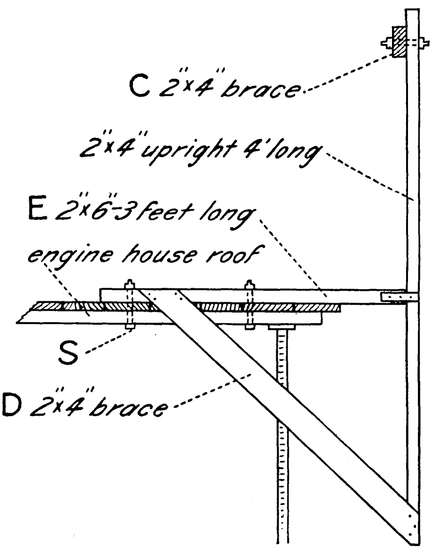

FIG. 14.—Method of fastening spray attachment to orchard sprayer

The discharge disk must be renewed occasionally, because the continued friction of the liquid wears away the edges of the opening, enlarging it and increasing the rate of discharge, so that the material is wasted, and eventually it becomes impossible to maintain the proper pressure.

There is some difference of opinion as to whether the nozzles should point directly downward or slant backward. The writer has tried various angles and failed to find any advantage in one position over the others.

The character of the spray produced by a plain nozzle of the type described in the foregoing paragraphs depends principally upon the pressure. With pressures below 75 pounds many of the particles of spray are so large that they roll down the surfaces of the foliage, collect in drops, and fall to the ground. At 75 pounds pressure the particles remain separate long enough to dry and form a fairly even coating, and as the pressure increases the spray becomes finer and the cover more nearly perfect. As the success of the work depends largely upon covering as nearly as possible all the upper foliage, the pressure should not fall below 75 and might well be kept at 100 to 150 pounds.

TOOLS

The tools needed in fitting up and using a spray outfit are, in addition to the usual hammers and wrenches, two 12-inch or 14-inch Stillson wrenches and a pair of pliers. The cutting and threading of the pipe used for the boom can be done at a plumber's shop more economically than by buying the tools which would be required for doing the work at home.

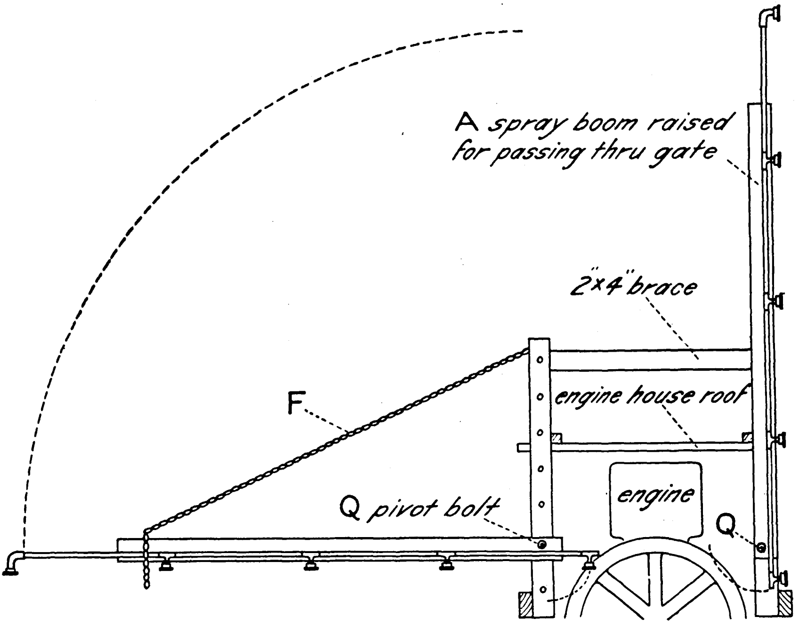

FIG. 15.—Rear view of orchard sprayer, with attachment in place. Note simplicity of arrangement for raising, lowering, and folding the booms

THE POISON

Arrangements should be made for obtaining the poison at the time when the machinery is being purchased or overhauled. Powdered arsenate of calcium is the most economical and effective substance for this purpose. It should be dry when purchased, free from lumps, and so finely ground that it will pass through a 200-mesh screen and have not the slightest gritty feeling when rubbed between the fingers.

The poison is weighed or measured for use at the rate of 2 pounds of the powder for each 100 gallons of water, and is stirred with a little water in a pail until it becomes a thin paste without lumps. It is then diluted and strained into the tank through brass milk-

strainer gauze, which may be mounted for the purpose on a hoop or a frame which fits the opening in the tank. Soap should not be mixed with calcium arsenate with the idea of making the latter stick to the foliage.

The materials and utensils should be kept free from dirt and lint, which later might cause clogging of the nozzles, and when cloth is used for straining liquids or covering containers it should be canvas or muslin and not a linty fabric like burlap. The spray liquid should be mixed just before it is to be applied, and kept stirred up until it is all used, to prevent the settling and wasting of the poison and the clogging of the pipes.

APPLICATION OF THE SPRAY

The spray outfit is ready for work when the tank, pump, pipes, and nozzles have been cleaned and, together with the engine, tried and found to be in working order and regulated so as to deliver 100 gallons of spray mixture per acre and maintain a pressure not lower than 75 pounds.

The beginning of a warm period is most favorable for spraying, because in warm weather the larvae feed more freely, as it is desirable to have them do for several days immediately after the application of the poison. If the poison is applied just before a cold spell, the weather may cause some of the feeding to be postponed until the alfalfa has grown a few inches and provided fresh unpoisoned food for the larvae. Nevertheless, good results have usually been obtained in spite of unpromising weather, and all that is necessary is to give the poison a chance to dry thoroughly upon the foliage before it is exposed to storms.

One man can operate a traction sprayer, two men are needed for a power outfit, and two to four for hand pumps, depending upon the size of the pump.

Thirty acres can be sprayed in a day with a 10-nozzle outfit, at a cost of $1 to $1.25 per acre. Results can be seen in from three to five days when many dead larvæ can be found and the field resumes its growth.

DANGER OF POISONING LIVESTOCK

The arsenic content of sprayed hay ranges from less than 1 grain in terms of white arsenic to nearly 29 grains for 30 pounds of hay, and is usually between 5 and 10 grains. The exceptionally large quantity of 29 grains in one day's ration is within the limit of tolerance of horses and cattle.[8] It is, therefore, entirely safe to feed sprayed hay to livestock, and there need be no case of arsenical poisoning unless white arsenic, sodium arsenite, or some equally virulent poison is substituted, through carelessness or ignorance, for calcium arsenate. It is important, however, for the man who sprays alfalfa with any arsenical compound to know the symptoms of arsenical poisoning, so that he can distinguish between that malady and colic, overeating, and starvation, the two former of which it is popularly but mistakenly supposed to resemble, and the latter of which is actually much like it.

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[8] REEVES, G. I. THE ARSENICAL POISONING OF LIVESTOCK. Jour. Econ. Ent. 18: 83–89, 1925.

Arsenical poisoning is produced only by a large dose of arsenic which is absorbed from the intestines into the circulation and attacks the liver. In severe arsenical poisoning there occurs an overintoxication resulting in an actual destruction and conversion into microscopic fat of the cells of liver tissue proper within their framework of connective tissue; and the liver loses its ability to eliminate poisons. In case of a dose sufficient to cause poisoning there is always a considerable quantity of arsenic found in the liver; that is, from 10 to 15 times as much as in the other tissues of the body.

Arsenic produces no lesion of the bones, such as rickets; its effect upon the nutrition of the body, when given in medical doses, is of an opposite character. If an animal is anemic and the nutrition is faulty, arsenic is administered and seems to have the power of taking the place of iron in the red blood corpuscles.

Arsenic does not affect the lungs or trachea except as a tonic, and there is no shortness of breath except as a consequence of pain and shock to the nervous system in acute cases or of stiffness in front of the ensiform cartilage in chronic poisoning.

ARSENICAL DUSTING

The use of calcium arsenate in the form of dry dust offers many mechanical advantages, such as getting rid of the great weight of water used in spraying. The dust is applied by means of a traction-driven or power-driven fan or blower, or by airplane, and the mechanical problems involved have been satisfactorily solved. The effect upon the crop has been in some cases even better than that of spraying, but until greater uniformity of results is obtained it can not be recommended.

OTHER METHODS OF CONTROL

Other methods of control, such as pasturing the first crop, and steaming, burning, and brush-dragging the stubble, are of limited usefulness, but are too expensive or interfere too much with the farm plan to be generally practicable. Substitution of other forage crops has helped to a small extent, but in spite of weevil damage and the cost of preventing it, alfalfa remains the most profitable forage for most of the territory now infested by the weevil.

CONCLUSION

The most baffling feature of the alfalfa-weevil problem is that, in climates where slightly abnormal weather may prevent weevil damage for a given year, growers tend to persuade themselves that they will never again find it necessary to control the pest. The result is that the next attack finds them off their guard and a crop of hay is lost. One year of unpreparedness in such a case is more costly than many years of preparation which prove unnecessary. Since weather conditions are uncontrollable, it is safest to assume that the only insurance against damage by weevils is a spray outfit and a supply of calcium arsenate.

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